Enhancing Egress Drills: Preparation and Assessment of Evacuee Performance

Article *in* Fire and Materials · May 2017

DOI: 10.1002/fam.2448

Published as: Gwynne S.M.V., Boyce K.E., Kuligowski E.D., Nilsson D., Robbins A., Lovreglio R., Roy-Poirier A. and Thomas J.R., 2017, Enhancing egress drills: Preparation and assessment of evacuee performance, *Fire and Materials,* DOI: 10.1002/fam.2448

Enhancing egress drills: Preparation and assessment of evacuee performance

S.M.V. Gwynne[1,*,†], E.D. Kuligowski[3], K.E. Boyce[2], D. Nilsson[4], A.P. Robbins[5], R. Lovreglio[6], T.J.R. Thomas[1] and A. Roy-Poirier[1]

[2]*Ulster University, Coleraine, UK - [3]National Institute of Standards and Technology, Gaithersburg, MD, USA - [4]Lund University, Lund, Sweden - [5]JensenHughes (Canada), Toronto, Canada -[6]University of Auckland, Auckland, New Zealand*

SUMMARY

This article explores how egress drills—specifically those related to fire incidents—are currently used, their impact on safety levels, and the insights gained from them. It is suggested that neither the merits of egress drills are well understood, nor the impact on egress performance well characterized. In addition, the manner in which they are conducted varies both between and within regulatory jurisdictions. By investigating their strengths and limitations, this article suggests opportunities for their enhancement possibly through the use of other egress models to support and expand upon the benefits provided. It is by no means suggested that drills are not important to evacuation safety—only that their inconsistent use and the interpretation of the results produced may mean we (as researchers, practitioners, regulators, and stakeholders) are not getting the maximum benefit out of this important tool.

1. INTRODUCTION: WHAT IS AN EGRESS DRILL AND WHAT ARE ITS BENEFITS?

An egress drill is defined here as a preplanned simulation of an emergency evacuation for a specific incident scenario.[i] In conjunction with other events (eg, strategic exercises, collaborative exercises, information sessions, and walkarounds[2, 3]), drills may be used to improve the performance of the occupant population and/or staff present and active during an emergency. Here, it is assumed that egress drills are primarily targeted at people within the structure of interest, rather than arriving emergency responders.[4, 5] Drills are typically performed on the basis of fire/building regulatory requirements applicable to the jurisdiction in question. Given political, social, and environmental developments, there are new hazards (both fire and nonfire) that may require an emergency response (eg, evacuation due to terrorist attacks or severe weather events). Coupled with this are projected demographic changes.[6] Over the last 25 years, obesity rates have approximately doubled to 12% in Sweden, 25% in the United Kingdom, and 35% in the United States and are continuing to rise.[6] Similarly, the old age dependency ratio (the proportion of adults aged 65+, relative to the remaining

*Correspondence to:Steve Gwynne, National Research Council, Ottawa, Canada.

†E-mail: steven.gwynne@nrc-cnrc.gc.ca

[i]The NFPA Guidance on All Hazard Emergencies defines an All-Hazard Drill is as follows: "A training exercise in which building occupants are familiarised with and/or practice the procedures for remain-in-place, in-building relocation, partial building evacuation, and total building evacuation, in accordance with an Emergency Action Plan. From NFPA Guidelines." Berlin et al differentiate between drills and exercise—drills seen as an attempt to enhance familiarization of individuals within a single organization, while exercises operate at the organizational or multiorganizational level.[1]

adult population) for Sweden has risen from 18% in 1960 to 32% in 2015 and is projected to rise to 41% in 2050.[7, 8] Similar trends are expected elsewhere. This means that there is an increasing variety of incident scenarios that need to be addressed by drills[ii] and that more preparation and resources may be required to adequately address these more varied situations and vulnerable populations.[1]

Egress drills are a *model* of an emergency evacuation from a particular building.[9][iii] As with all models, drills represent a cluster of simplifications and much of the model's value relies on the nature and extent of these simplifications. Ideally, a typical occupant population, the safety staff[iv] and the procedures expected during a real incident should be present during the drill, allowing more confidence in the similarity between the drill and reality.[v] The potential for this similarity is one of the strengths of the egress drill model—as it potentially involves actual members of the target population in their host environment that represent conditions that might be experienced by a subpopulation of evacuees in a real incident. It is apparent that where these elements are in place, the drill model can potentially approximate real-world conditions, at least in the initial phases, where incident development and evacuee exposure is at a minimum. This is useful indeed.

Given this potential, an egress drill is one of the most important tools available to the safety manager and provides an ongoing means of influencing the response to a potential future event. Typically the egress drill is seen as an opportunity to (1) train the evacuating population in the emergency procedure and the safety staff in their roles in the procedure during a representative scenario and/or (2) assess the performance of the population, procedure and staff under the same scenario. These are both extremely important objectives. These objectives are expanded when research applications are considered—with potentially a broader range of scenarios explored and more rigorous methodologies used.[vi] It is suggested here that the benefits and limitations of the egress drill are not widely or consistently appreciated. Additionally, there is inconsistency in how egress drills are organised and how they are conducted.[12] As a consequence, safety managers may not be fully exploiting the potential benefits of the egress drill. The subsequent discussion is an attempt to illustrate this situation and suggest enhancements.

This article explores how egress drills are currently used given current regulatory requirements, their estimated impact, and the insights gained from them. Alternative measures are discussed, and the relative strengths and weaknesses of the approaches are outlined according to the key training and assessment objectives. It is critical that such objectives are met and that drills are used consistently and appropriately to meet them.

2. WHAT DO WE KNOW ABOUT EGRESS DRILLS?

In this section, we discuss how egress drills are used to aid *research* (and subject matter understanding) and what insights egress drills provide in this regard. We also briefly touch on research previously conducted to better understand the effectiveness of drills/exercises,[vii] to identify the many ways that drills might influence performance—and the discrepancy between our understanding of life safety applications and those in adjacent fields. This discussion is presented to identify the factors that influence the impact of egress drills on performance, derived from the research community, and how this information might influence the questions asked by regulators and the manner in which they regulate the performance of drills. This is somewhat based on the assumption that researchers are interested in a broader set of factors and interested in them in more detail than routine applications.

[ii] Or other methods of assessment.

[iii] Fioretti defines a model in the following terms: "Models are simplified reproductions of portions of reality that, if validated, are still able to capture a few of its essential properties."[9]

[iv] Safety staff are occupants in charge of managing/directing the evacuation of other building occupants and/or emergency service personnel.

[v] Procedures might include total/partial evacuations, staged/simultaneous approaches and may require the deployment of a range of different human and technological resources.

[vi] The reader is referred to the ongoing efforts of ISO TC92/SC4/WG11 TG for the design of experiments.[10]

[vii] Texts address different events and refer to "exercises" and/or "drills." We will typically use the term 'drill' as a generic term, but use the term used by original authors when presenting original examples (eg, exercise and drill).

Hence, safety managers, regulators, etc may learn from reviewing the superset of factors examined and methods used by research and selecting the most important factors at the appropriate level of refinement - to ensure that they maximize the effectiveness of the drills used.

The performance of drills may address performance at a number of different organizational and procedural levels. These include the performance of the following:

- an individual act (eg, operating a fire extinguisher and a panic bar),
- an individual role (eg, a floor warden and a buddy),
- a group (of roles) defined within the procedure (eg, floor sweepers for a particular location),
- the interaction between different groups (eg, security staff, wardens, and buddies),
- the planned procedure (eg, phased evacuation),
- the interaction between different procedures (eg, the emergency evacuation and an extant security procedure),
- the building (eg, the time for the entire population associated with the building to be evacuated to a place of relative safety),
- multiple external agencies responding to the incident (eg, the fire service, paramedics, and police service), and
- multiple building and locations involved in the incident(s) (eg, the loading of the arrival of multiple building populations at a shared assembly/refuge area).

Drills can be conducted to enhance or assess performance at each of these various levels of refinement. These levels have different effects on performance and provide different indicators of success. The results of one level cannot easily be inferred from another. Research is particularly prevalent at the extrema of these examples in adjacent fields (the effectiveness of enhancing tasks and large-scale exercises); however, there is little research on the effectiveness of egress drills on enhancing evacuee performance at any of these levels in regards to fire incidents. Some examples are now presented.

Outside of evacuee performance, there has been considerable effort to understand the impact of drills at different levels of granularity and organisation (eg, individual tasks, agency response, and multiple agency response to large incidents[2, 4, 11–13]) and in different environments (eg, medical practice, natural hazards disasters, and civil unrest). Although not directly related, this research can be instructive for specific aspects of emergency planning in the built environment—helping to highlight opportunities and pitfalls.

Berlin and Carlström observed 19 collaborative exercises to determine what emergency personnel learned from their involvement.[2] They distinguished between collaborative exercises (focused on integrating responses of staff from different organisations), strategic exercises (assessing the impact of the procedure used), and drills (focused on enhancing individual knowledge). In their research, they focused on the impact of collaborative exercises on the target population. Berlin and Carlström drew several conclusions[2]:

- The scenarios typically examined were unrealistic, linear, and path dependent in nature (ie, strictly controlled and predetermined); scenarios that are not credible, insufficiently complex, or iterative.
- Participants did not need to adapt to the conditions faced or demonstrate flexibility in their responses. Instead, they had to perform simple, predetermined actions with which they were already familiar. They did not feel tested during the event.
- There was little opportunity for participant decisions/actions to fail and therefore for participants to learn from their experiences (ie, from their mistakes). This was due to the controlled/linear nature of the event, the observations made and the debriefing provided.[4]

There may be good underlying reasons for the aforementioned elements to be present. For instance, to reduce risk of injury, to ensure that a specific procedure is tested, and to control the nature of the scenario examined. However, the limitations presented by these elements are apparent and are translatable to smaller scale building egress drills.

There is much work on the impact of training/drills on the performance of emergency personnel—on their ability to perform individually and as teams in response to life-threatening situations (eg, US

Navy smoke divers and firefighters).[14–21] Although the target population may be qualitatively different, with different baseline levels of expertise and experience, the methods and metrics used to assess the impact on performance may be useful when examining the effectiveness of fire egress drills.

There is also considerable research in (and application of) highly technical training activities, limited to individuals or small groups, such as commercial piloting.[17] Here flight simulation is frequently used to enhance pilot familiarity with expected protocol, exposing them to the array of scenarios that they might face (which would not be ethical or practical through actual flying time), and allow them to understand and learn from their failures. Flight simulation has one huge advantage over egress drills in that the performance of the pilot in simulated and real-world conditions can be directly compared (albeit in routine scenarios) allowing the impact and credibility of flight simulation to be better understood.

Research is also available on the effectiveness of outreach and clinical programmes on improving the performance of cardiopulmonary resuscitation—both in the execution of cardiopulmonary resuscitation procedures by medical staff and the public and the suitability of this method for reducing health issues.[18–21] A number of methods are used to deliver and assess this effort. As noted by Hamilton,[18] "strategies that improve performance and retention of cardiopulmonary resuscitation skills and knowledge include video self-instruction, peer tuition, and computer-based teaching tools."

The existence of these examples (and there are many more) demonstrates that it is possible to enhance performance, to assess the performance levels of experts and nonexperts in an array of situations, and to understand these different processes. It also prompts questions regarding the detail and consistency with which such training and assessment are conducted in fire safety.

Human behaviour in fire has frequently used egress drills as a resource to collect data, gain understanding of evacuee behaviour, procedural design and to aid model development.[22, 23] Egress drills have provided a convenient *field laboratory* for evacuation researchers, especially during the formative years of the field, above and beyond their original purpose of enhancing life safety.[22–38] This research involved the observation of routine and modified drills performed to satisfy research objectives significantly beyond those of the regulatory requirements—collecting data on specific elements of evacuee performance (eg, pre-evacuation times[24–26] and travel speeds[27–30]), to assess the evacuation of different occupancy types (eg, apartment blocks,[31, 32] hospitals,[33] and schools/universities,[25,34]), and to examine the impact of different procedural elements (notification type,[35] actions of staff,[33,36] etc), amongst many other factors that might influence performance (eg, culture[34,37] and firefighter activities[28,38]). Proulx conducted seminal work both exploring egress drills as a source for understanding evacuee performance[24,26,31] and refining the research methods required to organize and observe them.[22] This information enhances our general understanding of evacuee performance (and subsequently improves our evacuation modelling capabilities) and also the overall evacuation performance of the specific drills in question.[39–41] However, very little of the research conducted in human behaviour in fire addresses the impact of the execution of egress drills themselves on evacuee or procedural performance—neither in terms of the benefit of a drill nor the influence of drill frequency on performance.[viii] Therefore, the potential to use drills to assess evacuee performance are reasonably well practiced; the short-and long-term training benefits of these drills on evacuee performance are less well understood.

For the egress drill to be of use to researchers and safety practitioners, the evacuation scenario represented in the drill must be known (eg, the population, the building, the procedures, and the level of training), to ensure that the data produced are representative of the scenario of interest. The value (irrespective of the objective) of an egress drill will be influenced by a number of different design features:

- Scope—Do the scenarios examined by the drills reflect those real-world scenarios that might be expected at the building/location in question?

[viii]Some researchers have questioned whether the performance of an act has as big an impact on recall as a postevent debrief—reliving the performance of the act.[3,42, 43]

- Validity—Are the drills conducted in a credible manner such that the scenarios reflect expected real-world conditions?
- Insights—Do the drills capture the necessary information that allows its performance to be observed and assessed?
- Granularity—Is the drill conducted such that it engages the population at the desired level? For instance, looking at task performance, individual performance, group performance, procedural performance, building performance, etc.

It is also important for researchers to manage the observation process (so as not to unduly influence the drill) and ensure that the data collected are sufficiently comprehensive (ie, sufficient scope) and refined so that factors of interest can be explored rigorously (ie, sufficient granularity).[4, 5] The researcher needs to document the context of the event and the outcome of the event. In recent years, there has been considerable effort to enhance the methodology for collecting egress drill data—to address research requirements.[4, 5, 17] This has improved the value of the data collected and meant that we better understand the information to be collected, and the methods and technologies currently available to collect it. However, it is not clear whether the data collected during regulatory routine egress drills (without the presence of a researcher or third-party observer) are typically gathered using these research approaches and whether the data collected have the accuracy, scope, and granularity required to be of use. This may lead to issues of consistency and credibility regarding reported evacuation performance as required by the regulatory structure that has jurisdiction.

Egress drills can have a number of different training objectives regarding the effectiveness of the procedural response. As is apparent from the research highlighted above, the drills may operate on a number of different organisational levels (eg, the individual, group, subpopulation, company, floor, and entire building), and the drills might be used to enhance the following:

- the accuracy/speed of situational assessment by the target population,
- the accuracy/speed of goal identification in response to the situation (eg, the population quickly recognizes that they are to evacuate),
- the recall/understanding of the relevant procedures in place given the selected goal (eg, the population remembers that they are to evacuate via the nearest available exit),
- the identification of the human, nonphysical, and physical resources required to enact the selected procedure and then the subsequent use of and interaction with these resources,
- the accuracy/speed of decision making given the procedure and the resources available,
- the appropriateness of the actions selected (eg, the population uses exits that are the most efficient, defined as the "appropriate action"), and
- the speed of action completion and the action's impact on reaching the selected goal.

The precise manner in which these questions are addressed will be reliant on the granularity and scope of the event, the insights required, the required confidence in these insights, and the qualitative and quantitative observations made to assess the drill's impact on performance (see Table I).

Table I. Example observations that might be taken during a drill.

	Situation Definition	Procedural Response	Actions Taken
Qualitative	Accuracy of participant understanding given their definition of the situation.	Appropriateness of procedure selected given situation faced. Relevance of objective given situation faced.	Appropriateness of actions taken (as part of procedure).
Quantitative	Time taken to determine situation faced (eg, delay prior to executing procedure and pre-evacuation time).	Time taken to select procedure. Time taken to execute procedure (eg, evacuation time).	Effectiveness of action taken (eg, number of exits closed). Time taken to complete action performed (eg, time to exit from stairwell).

Similar considerations should also be explored by those interested in the impact of egress drills on the routine life safety of particular buildings and their populations—beyond research; for instance, regulators, safety managers, etc. These considerations will have a similar impact on the effectiveness and relevance of a routine drill: the considerations need to be examined to establish the impact of the drills on performance and/or on the current performance levels attained. A selection of the regulatory frameworks used to constrain and inform drill performance is now discussed, to derive the variability present and the discrepancy between current research and insights provided during routine drills.

3. WHAT DO REGULATIONS REQUIRE OF EGRESS DRILLS?

Internationally, a number of regulatory codes require the performance of egress drills.[44–60] A brief, but representative, selection is now presented. This is by no means exhaustive of the full scope of each regulatory structure described. This summary is not intended to judge the appropriateness of these regulations for their respective jurisdictions, but is instead intended to provide insight into the variety of regulatory requirements available and how this variety might influence the manner in which drills are conducted and subsequently influence life safety.

3.1. United States

NFPA 101 Life Safety Code 2015[44] specifies the number of times that a drill has to be performed (from section 4.7.2, "sufficient frequency to familiarise occupants"), who should be involved (from section 4.7.3, "all persons subject to the drill"), the prior knowledge of those involved (from section 4.7.4, "at expected and unexpected times"), and the nature of the scenario examined (from section 4.7.3, "emphasis shall be placed on orderly evacuation rather than on speed" and from section 4.7.4, "under varying conditions to simulate the unusual conditions that can occur in an actual emergency"). NFPA 101 goes on to provide more detailed guidance for specific occupancy types (both new and existing), including ambulatory health care, assembly, business, day-care, detention and correctional, educational, health care, hotels and dormitories, mercantile, and residential board and care. For instance, the following requirements are provided for new health care facilities: A fire alarm signal is expected to be sounded (section 18.7.1.4); infirm/bedridden patients are not required to be moved (section 18.7.1.5); drills will be conducted quarterly for each shift (section 18.7.1.6); if conducted between 09:00 PM and 06:00 AM, a coded announcement can be used, instead of audible alarms (section 18.7.1.7); and staff involved will have been instructed in the use of any evacuation devices and emergency procedures (section 18.7.1.8).

The occupancy-specific requirements in NFPA 101 define who should be involved in the drill, how frequently it should be performed and when it might be performed. Depending upon the occupancy type, the participants involved in the drill/training can range from staff members only (in ambulatory health care, for example) or employees (as is the case with mercantile) to all building occupants (eg, educational or business occupancies).[44] The frequency with which drills are performed also varies by occupancy. For example, some occupancies do not have a specified frequency requirement (eg, detention and correctional or mercantile), while others are required to perform a certain number of drills per year (eg, quarterly, 6 times a year, or at least once per month). Additionally, the time of day of the drill varies by occupancy. In some cases, NFPA 101 does not specificy the time of the drill other than to require that drills should be held at both unexpected and expected times. In some cases, the code provides additional specificity; eg, in ambulatory health care occupancies, "drills shall be conducted quarterly on each shift to familiarise facility personnel (including but not limited to nurses, interns, maintenance engineers and administrative staff)" (section 20.7.1.6). Requirements that mandate building occupants must participate in the drill also limit the timing for the drill; eg, for an educational occupancy, the drill must occur during normal school hours.

3.2. *United Kingdom*

In the United Kingdom, regulations[45–47] require that in sufficiently occupied premises (other than domestic), an "appropriate" person take responsibility for ensuring that premises reach required safety standards. This requires performing fire risk assessments, identifying hazards and people at risk, managing the risk, and developing and implementing appropriate emergency procedures in the event of fire. The process involves the development of an emergency plan, informing and instructing relevant persons on actions to be taken and delivering training to employees, particularly those with specific duties. Unlike many other regulatory approaches, the UK regulations do not specify the frequency or nature of drills but rather simply state, for example, that the responsible person "establish and, where necessary, give effect to appropriate procedures, *including safety drills*"(para 8.1[45]). The guidance produced by the Scottish government states that the frequency and nature of drills should reflect the levels of risk, stating that

> Fire drills should be carried out to check that staff understand the emergency fire action plan (including all relevant personal emergency egress plans), to ensure that staff are familiar with its operation, to evaluate the effectiveness of the plan and to identify any weaknesses in the evacuation strategy. The frequency and type of fire evacuation drill for each premises will be different and *should reflect the type of premises and level of risk*.[47]

Although the UK regulations themselves do not state precisely the required frequency of drills, the frequency is suggested in other associated documentary guidance.[48] For example the UK government's website www.gov.uk suggests that "you should carry out at least one fire drill per year and record the results. You must keep the results as part of your fire safety and evacuation plan." Other documentation produced by the Northern Ireland Fire and Rescue Service for small businesses suggests a fire drill should be performed at least twice yearly and at different times of the day.[49]

Additional information is provided in BS 9999 that relates to new build and building modifications.[50] BS 9999 superseded many of the BS 5588 prescriptive standards, instead using a structured, risk-based design. This approach, which is intended for structures that do not require a full fire-safety engineering approach to be adopted, allow designers to take into account both human and physical factors that is intended for structures. BS 9999 identifies the benefits of monitored evacuation drills, especially in newly occupied structures and outlines a number of considerations regarding egress drills:

- Drills should be conducted at least annually.
- The drill objective should be explained to staff. This objective might relate to testing procedures, training staff, establishing training effectiveness, testing communications, testing staff hierarchies, testing equipment, and establishing coordination effectiveness with emergency responders.
- Recognizes both the disruption of drills and the benefits (especially where the maximum number of intended people are involved).
- Drills should not be held at predictable times to ensure a lack of staff preparation.
- Those subject to the drills should not have prior knowledge.
- Different scenarios should be examined (including the loss of egress routes).
- Observers and reporters should be designated. Video recording is preferred as it enables a detailed comparison to be made.
- Drills should involve the procedures for evacuating disabled people, where possible.
- To maximize the lessons learned, a full de-brief should follow the drill.
- The results of any egress drill should be recorded at various levels of operation (ie, not just the final outcome).

3.3. *International*

The International Fire Code (IFC)[51] requires that drills are performed, that the frequency of performance be dependent on the occupancy type, and that conditions and drill times should be varied (section 405.3). The IFC makes specific reference to the objectives of an egress drill above: 405.1 Commentary: "Just as emergency operations and hazardous material response plans require operational drills to verify their continued viability and effectiveness, so too do evacuation plans require periodic implementation to gauge effectiveness in achieving their objectives."

Also, 405.2 commentary: "To utilize fire drills and the lessons that they teach to the best of their advantage, drills should be conducted on a regular basis to familiarize both staff and residents with the evacuation plan."

The IFC goes on to provide more guidance on the type of information that needs to be collected when an egress drill is performed. In section 405.5 on record keeping, the IFC identifies that information should be collected on those conducting the drill, the date/time of the drill, the notification method involved, the participating staff, the number of evacuees, the conditions simulated, the problems encountered during the drill, weather conditions, and the time required to complete the evacuation.

3.4. Canada

Division B of the National Fire Code (NFC) of Canada[52] addresses similar concerns in 2 key clauses: NFC Div. B 2.8.3.1

> Fire Drill Procedures: 1) The procedure for conducting fire drills shall be determined by the person in charge of the building, taking into consideration: a) the building occupancy and its fire hazards; b) the safety features provided in the building; c) the desirable degree of participation of occupants other than supervisory staff; d) the number and degree of experience of participating supervisory staff; e) the features of fire emergency systems installed in buildings within the scope of Subsection 3.2.6 of Division B of the National Building Code (NBC); and f) the requirements of the fire department.

The clause stipulates that the drill will be sensitive to the building, the population, the potential hazards, the procedural resources available, and the fire service. These issues are discussed further in associated explanatory material, which addresses the objectives of the drill and how the design of the drill influences meeting these objectives and the operational status of the building:

> NFC Div. B A-2.8.3.1.(1) A fire safety plan is of little value if it is not reviewed periodically so that all supervisory staff remain familiar with their responsibilities. A fire drill, then, is at least a review of the fire safety plan by supervisory staff. The extent to which non-supervisory staff participate in a fire drill should be worked out in cooperation with the fire department. The decision as to whether all occupants should leave the building during a fire drill should be based on the nature of the occupancy. It may be necessary to hold additional fire drills outside normal working hours for the benefit of employees on afternoon or night shifts, who should be as familiar with fire drill procedures as those who work during the day. If full scale fire drills are not possible during non-regular working hours, arrangements should be made so that night-shift staff can participate in fire drills conducted during the day-time.

The second clause suggests that the involvement of the occupant population in the evacuation is sensitive to the occupancy type; ie, that some buildings do not have to evacuate during the drill in accordance with their emergency procedure (should that even require a full evacuation). The second clause also addresses the frequency that the drill should be performed, which is again sensitive to the building type:

> NFC Div. B 2.8.3.2 Fire Drill Frequency: 1) Fire drills as described in Sentence 2.8.3.1 (1) shall be held at intervals not greater than 12 months for the supervisory staff, except that: a) in day-care centres and in Group B major occupancies, such drills shall be held at intervals not greater than one month; b) in schools attended by children, total evacuation fire drills shall be held at least 3 times in each of the fall and spring school terms; and c) in buildings with the scope of Subsection 3.2.6 of Division B of the NBC, such drills shall be held at intervals not greater than 2 months.[ix]

[ix]Group B are predominantly treatment and care occupancies.

3.5. New Zealand

In New Zealand,[53, 54] either drill/trial evacuation procedures[x] (a requirement for childhood or educational facilities[xi] and discretionary for other occupancy types) or an evacuation training program[xii] is outlined by the building owner in the application for approval for the evacuation scheme. This is required for most buildings except those with small populations.[xiii,xiv,xv] New Zealand regulatory evacuation drill requirements state the following[53]: the building owner is to undertake the trial evacuations at least twice per year; the drills should include all building occupants, except those with a disability[xvi] and those under supervision; the National Commander requires notification of the trial no less than 10 working days prior to the proposed evacuation; and the results have to be reported to the same commander within 10 days of the trial (including the time achieved and whether there were injuries). The New Zealand Fire Service[xvii] requires that the evacuation scheme lists the following[xviii]: (1) the designated place(s) of safety; (2) how the occupants are to be notified of the incident and their response; (3) the location of any firefighting equipment; (4) the location and type of relevant signs; (5) whether building work has been performed and whether it alters egress routes;(6) whether occupancy changes and whether this change affects the need to have an evacuation scheme; (7) the designated locations for those with disabilities unable to self-evacuate; (8) the methods of notifying the firefighters of the number of people at these designated locations; (9) the location of supporting equipment used to assist with evacuation and the training of designated people with such equipment; and (10) the names of those who need to remain at designated locations to assist.

3.6. Italy

The Italian regulatory code states that any workplace with more than 10 employees is required to conduct an evacuation drill at least once a year.[56] The employer is responsible for the procedure applied. The intended procedure is dependent on the size of the building (or organisation). In "small" buildings, the evacuation drill aims to let employees (1) walk through the evacuation routes;(2) identify the fire doors (when they are in place); (3) identify the location of alarm systems; and (4) identify the location of fire extinguishers. In "large" buildings, it is acceptable to perform several partial evacuation drills instead of one global evacuation drill. Such partial evacuation drills should lead the evacuees to a point where they can identify the subsequent routes to a safe/assembly area. Moreover, in large buildings, the assessment of the evacuation drill can be done by several evacuation wardens who need to report possible flaws of the evacuation procedure to the employer. Therefore, the purpose of drills is (1) to train the employees and (2) to assess the evacuation procedures. Firefighters do not need to be alerted. Evacuation drills should be avoided when the building is overly crowded and/or when there are elderly or infirm people located within the building population. Employees in charge of the safety of the working environment are excluded from the evacuation drills. An additional evacuation drill is required within the year if a previous evacuation drill has shown a series of deficiencies, the number of occupants has increased, and/or modifications have been made to the structure that influence the routes available. Should several organisations occupy the same building (eg, different companies), these organisations would then need to collaborate to perform an evacuation drill.

[x] Clauses 2 to 4 of schedule 3.[54]
[xi] Clause 17 of part 2.[54]
[xii] Clauses 5 to 7 of schedule 3.[54]
[xiii] Schedule 1, buildings to which part 1 applies.[54]
[xiv] Section 21E.[53]
[xv] Quotations from the codes are stopped at this point given the space available.
[xvi] Such experiences were reported in workshops conducted as part of Accessible Egress Pilot Workshops Summary.[55]
[xvii] https://onlineservices.fire.org.nz
[xviii] Clauses 17 to 19 of part 2.[54]

3.7. Sweden

In Sweden, systematic fire safety work is required by law according to the legislation relating to fire prevention[57] and safety in the workplace.[58] According to Statens räddningsverks författningssamling (SRVFS) 2004:3, there needs to be a plan for fire safety training, and all training efforts need to be documented; however, egress drills are not explicitly mentioned in the legislation. Similarly, Arbetsmiljöverkets författningssamling (AFS) 2001:1 mentions training in the area of evacuation without specific mention of drills. Although egress drills are not explicitly required as training measures in the legislation, they are often recommended by local authorities (refer to Räddningstjänstensyd[59]). In the past, egress drills were a requirement for all places of work,[59] but information regarding what the drill should entail and why it should be performed was very limited. AFS 1993:56 simply stated that egress drills should be performed on a regular basis but that the time interval between drills should depend on the needs of the workplace. Past legislation also stated that egress drills could be replaced by information efforts if this was expected to result in the same knowledge as drills.[60]

From this review of various international regulations and standards, it is apparent that neither egress drill requirements nor objectives are consistently specified. Although a degree of flexibility is warranted, the absence of detail does allow safety managers a great deal of scope within each of the regulatory structures—particularly in the scenario examined, the data collected and how the data are used. Close third party scrutiny might allow for these choices to be checked for consistency and credibility, but it is unlikely that it would address all of the drills performed for all buildings in a jurisdiction.

A great deal of research is available regarding the factors that influence evacuee movement and (to a lesser extent) evacuee decision making.[61–65] For instance, how evacuees cope during an evacuation; their sensitivity to information/experience; their capacity to perform under time constraints[64]; and the range of physical, cognitive, sensory and experiential capabilities present. Very little directly relevant research is available that allows us to answer the following questions: (1) What impact does an egress drill have upon evacuee performance? (2) How much does repeatedly being exposed to egress drills increase a target population's performance over a single exposure? (3) How frequently should egress drills be performed? This limits the guidance available for those developing regulatory codes.[xix]

4. WHAT QUESTIONS SHOULD WE ASK WHEN DESIGNING AN EGRESS DRILL?

Wilson identified a number of elements that should be considered when designing a training programme for disaster response (focusing on the preparedness of small groups)[66]:

- the training objectives,
- the population that requires training,
- the training method that is to be used,
- the preparation of training materials,
- the delivery of the training programme,
- the evaluation of the effectiveness of the training delivered, and
- the auditing of the process to enable the programme to be updated to ensure that it fits the original purpose.

It is worth considering how consistently or widely these elements are applied in life safety applications, when designing and implementing egress drills.

For both familiarisation and performance assessment, egress drills need to be as representative of real-world conditions as possible. The closer the approximation between the egress drill and real-world conditions, the more indicative the performance will be, and the more valuable the training/familiarization will be for the target population. The regulatory structures mentioned above attempt to ensure that drills are performed in an effective and reasonable manner given the

[xix] Any discrepancies between regulatory needs and research available might reasonably influence the direction of future research efforts.

occupancy in question. However, it is apparent that the egress research community grapples (to varying degrees of success) with a number of key questions related to egress drills:

- What is the objective of the drill? What should be the objective of the drill?
- How often should drills be performed to enhance performance without desensitising occupants and causing undue disruption?
- What proportion of egress drills should be used for training and/or for assessment of performance?
- What incident scenarios should be examined as part of an egress drill? What incident(s) should be assumed?
- Who should be involved?
- What procedures should be tested? What technologies, staff, and third parties should be involved?
- How realistic can/should the drill be?
- Who should know about the egress drill in advance?
- What data should be collected from the drill and how should it be reported?
- How should the data be collected? What technologies/methodologies should be used?
- What constitutes a successful outcome for a drill? What is the benchmark?
- Who should monitor the drill?
- What information should be reported and to whom (eg, to staff, evacuees, and management)?
- Do these requirements rely on the types of occupancies involved?

Similar questions should certainly be asked by regulatory authorities when determining requirements, and by those supervising a drill to determine whether its performance is fit for purpose.

All of these questions should be considered when designing and implementing a drill—ideally information on these questions should be provided in any regulatory structure requiring the performance of a drill. However, the responses to many of these questions are not well understood and may be compromised by issues that do not relate to the objectives of the drill itself; for example, issues of cost, safety, convenience, and practicality. These issues will affect any attempt to approximate a real evacuation—an approximation that might be used to assess or influence evacuation performance. This poses another question: How good an indication of a real evacuation is provided by an egress drill?[xx]

5. WHAT ARE THE LIMITATIONS OF EGRESS DRILLS

As with any approach at influencing or assessing egress performance, egress drills will exclude a number of factors that might be present during a real incident—its underlying model will be a simplification of the real world; eg, the lack of preparation and warning in a real incident, presence of active emergency personnel, presence of fire effluent (to which some individuals might have been exposed, leading to psychological, physiological, or behavioural developments), etc. To understand the value and appropriateness of the output produced by any egress model, it is critical to assess the distance between the model and reality; between the assumptions made in the model and the underlying factors that would be present in the real-world.[xxi] The proximity between real-world and the egress model[64] is limited by considerations that preclude the representation of a number of key factors. Given the involvement of human participants, the following considerations are particularly relevant to an egress drill[xxii]:

1. Financial/organisational: Resources are needed to design, organise, execute, and analyse an egress drill. Attempting to generate realistic evacuation conditions may be enormously disruptive

[xx]For instance, where a real fire has occurred in a building, how representative was the scenario examined during egress drills performed prior to the incident and how representative was the evacuee performance of that exhibited during the real incident?

[xxi]This assessment is complicated as the distance between model and reality will differ for different agents/evacuees, according to their experience.

[xxii]Although here they are being applied to egress drills, these considerations could and should also be applied to the other types of models.

to the routine operation of the building—before, during, and after the drill—which will incur costs due to the services lost. In addition, organisational and external resources may need to be diverted to the performance of the drill; for instance, staff, equipment, etc. The performance of frequent and representative drills may then be too costly in the disruption in building services, preparation, and analysis. Authority is required to organise and perform egress drills—especially drills that might cause significant disruption to business and financial loss.

2. Ethical[xxiii]: Attempting to reproduce credible real-world conditions may place those involved in the drill at undue risk of injury. A key consideration in the conduct of drills is the outweighing of risks to drill participants with the potential insights provided/training benefits to those taking part and to the general public, which are often difficult to quantify. For instance, if a sense of evacuee urgency and route loss leading to stair congestion is represented during a drill, then these conditions might expose the evacuating population to trips, falls, undue stress/anxiety, or even crush conditions. Conversely, these conditions may also add to the realism and credibility of the conditions faced. The concern over harming participants might also limit the involvement of those who might be exposed to injury or discomfort simply by taking part in the drill; eg, participation of vulnerable populations may expose them to fatigue, trips/falls, or discomfort. This is especially important as these subpopulations may have an important influence on overall evacuation performance and also require additional training given their vulnerable nature and training of those that may provide assistance.[xxiv] Ethical concerns may also prevent the performance of a drill at a certain time (eg, in winter or during the night). Safety concerns may also preclude the adoption of certain emergency procedures given the risk posed by their use (eg, using evacuation devices and descending numerous flights of stairs) or the involvement of people who might more effectively be used elsewhere during real incidents (eg, fire service who might reasonably need to address real incidents). The inclusion of the factors mentioned may enhance the realism of the drill scenario but may also raise ethical concerns regarding the short- and long-term health of participants. It is also important to consider the distribution of risks versus benefits. A drill that directly benefits the participants by, for example, making them better prepared for future events is considered more ethical than a drill where the benefits are simply through the nature and performance of the drill itself.
3. Methodological: If interested in evacuee performance, it may not be possible to sufficiently instrument the building to collect the needed data (eg, route use and travel speeds), at the level of refinement needed (eg, examining the performance of those with an impairment or from a certain floor), and identifying the underlying factors (eg, congestion on stairs, performance of those with movement impairments, and individual actions) that influence the outcome of interest. It may be difficult to collect data without influencing the outcome of the incident (eg, people seeing the cameras and staff). It may also not be possible to deliberately manipulate underlying factors in a controlled manner. For instance, enforcing the initial location of the population, ensuring route use, etc. This might limit the potential to recreate real-world scenarios of interest. It may not be possible to deliberately manipulate the necessary factors in a sufficiently controlled way to expose the target population to scenarios of interest at the level of detail required. For instance, given the limited number of drill scenarios typically examined, it may be necessary to (1) require individuals to perform specific tasks and assess this performance, (2) require a structure to be evacuated using a specific procedure, and (3) then have the outcome of this procedure assessed simultaneously. These activities and assessments occur at different levels and may require different forms of observation and different levels of effort. It is suggested that the routine performance of drills sacrifices some of the scrutiny and resources required to focus on one level at a time—potentially the "lowest hanging fruit," especially when resources are an issue. As noted by Berlin and Carlström, there is value in having scenarios of sufficient

---

[xxiii] Should a drill be conducted purely for research, then further ethical restrictions will be in place, as the participants will be taking part in an event that they would otherwise not be expected to perform. There will also be additional issues of consent.

[xxiv] However, vulnerability is not static. For instance, evacuating a fit, unimpaired population down the stairs from the 75th floor of a high-rise building may make them relatively vulnerable in comparison to the evacuation of a similar population from the third floor of the same building.

complexity to require participants to adapt—demonstrating individual and organisational flexibility in addressing the challenges faced.[2] As with any model, although necessary, it is not sufficient for only the initial scenario conditions to be represented and then the final model's output compared against expectation. This method excludes several points of assessment: (1) the evolution of local conditions that emerged during the incident, (2) the evacuee performance during the drill in response to these conditions, and (3) the progression of the overall event. In the assessment of any model, simply identifying the initial conditions and then examining the final output is insufficient justification to deem the model credible.[64]

4. Supervisory: In many cases, the existence, frequency, or nature of the drills are not monitored or scrutinised by authorised third parties. This might be due to a lack of resources forcing inspection/supervisory agencies to focus on high-risk properties. Little control is then exerted over the manner in which drills are normally executed, the scenario examined, the data collected, the manner in which the data are analysed and the use made of the data collected. Wilson noted that ensuring that training and exercises provide a return on the investment made through evaluation is critical.[66] Sinclair et al stated that "without the ability to gauge the effectiveness of an exercise its usefulness as a means of testing of plans and capabilities is unfounded."[12] Anonymity of those individuals monitoring drills might also be useful to prevent direct interaction or influence given the assessment produced. In 2009, the Auditor General of Canada reported on whether government departments complied with regulations on egress drill performance.[11] They found that although departments were required to perform yearly drills, 33% could not show that they had done so. They also noted that there was no government-wide means of observing and documenting the performance of these drills. Drills were then potentially not being performed according to the requirements and were not being consistently monitored when they were performed. If representative of common practice, such issues mean that any shortfalls in the methodology adopted or compromises needed given financial, organisational, or ethical concerns may not be consistently identified or documented, preventing assessment. In addition to the potential lack of consistent oversight, there is inconsistent guidance on the data that should be collected, compiled and reported, and how this should be achieved. This hampers the ability of third parties (eg, authorities having jurisdiction, and safety managers) to scrutinise the scenario being examined and the impact of the exercise on the target population. Without consistent and credible data collection on the scenario conditions and the outcome of the drill, it is impossible to effectively assess whether a drill was performed as required or whether its impact was as expected.
5. Statistical: Drills are performed periodically (given the concerns highlighted above and stated regulatory requirements). Each drill represents an instance of a scenario—a single data-point from within a distribution of outcomes that might reasonably be expected for a particular scenario given minor perturbations in the initial conditions. A scenario may possibly be repeated a number of times over a period. For instance, a midrise office block may be completely evacuated using all of the staircases available several times over several years. Given the appropriate controls, this set of results may eventually provide some statistical foundation for any conclusions made. However, if this is the case, then many other possible scenarios would likely not be drilled; for instance, where a particular stair is not available, where the population is distributed differently, etc. Given the current number of drills performed, emergency managers are then torn between producing a reliable understanding of a single scenario, or limited understanding of several scenarios.
6. Pedagogical: Given the challenges posed by the drill's organization, it may be difficult to ensure that those involved are subjected to training for all of the tasks that they may be expected to perform in a real incident. In essence, the drill may focus on the overall performance of the procedure (high-level performance), as opposed to individual activities. This may then focus on making participants more familiar with the procedure, rather than having detailed understanding and training in the set of tasks that make up the procedure. Doing both at the same time would be challenging indeed. In addition, it is often impossible to ensure that the entire desired population is present for the drill (especially if forewarning is provided) and to ensure the degree of recall of the entire population (especially as time passes).

These concerns limit the accuracy and credibility of the model used (eg, egress drill) in a number of ways. Firstly, the results produced may not be a good indicator of real-world performance given the limited number of data-points collected and the insights gained from them (see point 5). This is especially the case if the drill is neither performed nor documented as mentioned above (see points 3 and 4). A single drill produces only one overall evacuation time (and one set of lower level indicators). It cannot be assumed that this time is necessarily representative of the range of different outcomes that might be produced during a real evacuation involving the same scenario. Secondly, the scenarios examined may not be representative of those that might actually occur (see points 1-3 and 5); for instance, in terms of the information available, the routes lost, the size and distribution of the population involved, the conditions faced, etc. A relatively narrow range of scenarios will typically be examined, providing little insight into other emergency scenarios. Viable scenarios will be limited by expediency and risk aversion. In addition, the scenarios selected may be biased to favour simple planning and execution (depending on the resources and expertise available), further skewing the insight provided. Thirdly, only a limited amount of data are routinely collected; for instance, focusing on the overall clearance time of the building rather than the contributing factors. It may not be sufficient to provide insight of the underlying factors that lead to this performance. The diagnostic value of the drill (ie, understanding what led to the overall performance) is then limited given the type and accuracy of data collected and the resources available. Finally, it is unlikely that the accuracy and credibility of the drill is independently assessed to the necessary degree.

All of these limit the usefulness of the insight into evacuation performance that an egress drill provides and its subsequent impact on life safety (see point 4). In addition, if addressed simultaneously, the competing objectives of an egress drill can undermine its value (see point 6). As mentioned in the IFC requirements,[51] drills are typically performed for two distinct reasons: to assess the performance of a procedure and to train the population and staff of the procedure in place. These are both important objectives. Egress drills are a useful model in addressing each of these objectives. However, it is challenging (if not impossible) to simultaneously achieve these objectives during the same drill. For instance, where staff members (whose influence might otherwise not be present during a real-world evacuation) intervene to assist training and occupant familiarisation, the overall performance may be unduly optimistic as a result of the additional assistance provided. Where there is no staff intervention of this type, then the training objective might not be met, as the procedure may not be executed as expected or individual tasks not performed as desired. (This latter situation may help familiarize the occupants involved with undesirable procedures and tasks.) Training staff intervention may occur in a detailed debrief—where the performance of individuals and the procedure used are assessed and feedback provided. This would provide instruction without compromising performance. This requires detailed and comprehensive monitoring, analysis, and presentation of the assessed performance—all of which requires time and resources. Given the original expense of the drill, such intensive debriefing may be considered too costly and is certainly not common place.

Given the limited number of times that drills are performed (due to the considerations mentioned above, see points 1-5), it is often assumed that a drill is able to address both objectives (familiarization and assessment) simultaneously. This is rarely, if ever, the case. This may encourage a false sense of safety[xxv] in the robustness and performance levels achieved through the use of the emergency procedure; for instance, where performance has been enhanced by intervention/instruction, and where unchallenging scenarios have been examined.[xxvi] Training allows the improvement of performance through the provision of guidance and the familiarisation of the target audience with the procedure in place (and potentially practicing tasks within that procedure). Assessment requires an unpolluted measurement of the current performance levels achieved given current practice: the procedure in place, population distribution, population training levels, the nature of the incident, etc. It is designed to establish current performance levels to identify required actions

[xxv]It may also provide a false sense of security.

[xxvi]A case could be made that examining simple scenarios, and the resultant good performance, might increase evacuee confidence in the procedures making a calmer response more likely in a real incident. However, this would need to be balanced in the shortfall between the scenario(s) tested and actual scenarios that might be faced.

and new resources. A clear distinction has to be made; otherwise both objectives might be compromised.[xxvii] In addition, establishing respective benefits of the drill on performance becomes more challenging as the scenario becomes more complex and when outcomes on multiple levels are of interest. Assessment of performance during a drill is primarily interested in how people perform given current practice rather than how we want them to perform. One insight relates to current performance deficits, while the other relates to reducing this deficit.

6. SO WHAT? IMPACT ON THE CURRENT SITUATION

It is suggested that currently egress drills are not (1) used consistently, (2) used for comparable objectives, (3) sufficiently reported or monitored, and, most importantly, (4) are not used to their full potential. That is not to say that egress drills are unnecessary—or that they are not a useful model for understanding and influencing evacuee performance. However, there is insufficient scrutiny and guidance on the design, practice, reporting and oversight required. This undermines the value of what might otherwise be a sophisticated and important model of evacuation performance. Egress drills need to be fully exploited given the value of their results, the cost of performing them, and they are required internationally.

Just as undermining to a drill's value is the frequent attempt to assess evacuee performance and train participants at the same time. Where possible, a population needs to be trained, to ensure that they are familiar and practiced with the emergency procedure and their role within it. It is just as important to assess the effectiveness of this training and the robustness of the procedural resources in place—to determine the performance levels that can be expected during a real incident and enhancements to the drill itself.

Several questions then arise:

- How do we exploit egress drills more effectively to train and assess performance?
- What alternative models are available to influence and assess evacuee performance?
- How might we use egress drills and alternative models together?

The egress drill is one of several egress *models* available. A model will not be suitable for all scenarios and cannot represent any one scenario perfectly. Factors will be excluded as part of the simplification. Model use then needs to be clearly understood and justified given the application at hand; this applies to all models. In the previous discussion, we described how egress drills are often used to assess evacuation performance and/or train the responding population. A number of limitations have been identified. In this section, other egress models are identified to explore their potential to help meet the same two primary objectives, by complementing the egress drill model used. This involves identifying the strengths and limitations of the models discussed (including drills) and how these might affect meeting these objectives.

An egress drill is very much a simplified *model* of a real-world evacuation—a fact often obscured given that the building, the procedure, and population can often be the same as those present during a real event being represented.[xxviii] However, key factors are often deliberately omitted by design (such as environmental decline). In many instances, (for instance, in much of North America), a numerical assessment of evacuee performance would previously not have been necessary if a prescriptive design had previously been used. Therefore, where prescriptive regulations are used, the performance of an egress drill will likely be one of the few opportunities to quantify egress performance; ie, to see how effective the procedural measures actually are.

Other egress models include computational, physical, scale, engineering, conceptual, real-world, prescriptive, experimental, gaming, mental rehearsal, virtual, and table-top models, amongst others. [67–69] Each of these models has its own strengths and weaknesses. All of them make assumptions

[xxvii] This is especially the case where staff performance is substandard, requiring significant intervention.

[xxviii] Similar to the way that the sophistication of computer models can be obscured by the quality of its graphical user interface.

regarding evacuee behaviour and the scenarios to which evacuees might be exposed. The nature of these assumptions determine their value—in either quantifying evacuation performance or aiding in the training process. For instance, a number of computational simulation tools allow the relationship between underlying evacuee actions (eg, the routes adopted by simulated agents) and overall evacuation performance (eg, time to clear a floor, congestion on a stair, and the building) to be explored. A detailed description of these models can be found in the reviews developed by Kuligowski et al[69] and Gwynne et al.[67]

7. ALTERNATIVE EGRESS MODELS

A number of alternative egress models exist. These do not have the same capabilities or make the same assumptions. In the context of familiarising participants or assessing performance, there are several basic factors that can be used to differentiate the models and their potential contribution: *environment* (the physical space within which the event is conducted), *agency* (the degree of actor activity and influence during the event), *scenario* (the event narrative and path dependency of the event), and *feedback* (the insights provided to the actors by the event manager [model user]). Each model type is described in more detail below.

The following models are included here as they might possibly assist with the assessment or familiarisation of evacuee performance and may therefore reasonably complement egress drills in some form. A brief overview of the strengths and limitations of several of these models for egress training or assessment is presented in Table II.[70] This includes the following models:

1. Egress simulation tool—Computer simulation of an evacuation.[41] Initial scenario conditions are provided to the tool by the user that then simulates the progression of these conditions over time, depending on the response of a simulated evacuating population. With most tools, the user is able to passively monitor the conditions via a GUI as they evolve and the consequences of agent actions on the outcomes produced. Typically, data are generated on various aspects of the simulation reflecting the evolving conditions and the final outcome. As with the other computational approaches discussed, the user may have access to scenarios that would ethically be impossible to conduct in reality; ie, that place simulated evacuees in jeopardy.
2. Computational virtual/immersive environment/serious gaming—Participants are "located" within a virtual space allowing them to actively make decisions in response to the conditions

Table II. Model limitations and capabilities.

	Considerations (Derived from Discussion Presented in Section 6)							
			Methodological					
Egress Model	Financial/ Organizational	Ethical	Perceived Credibility	Scope	Potential Insights	Third Party Scrutiny	Statistical	Pedagogic
Egress drill	—	—	+	—	≈	≈	—	+
Simulation tool	≈	+	—	+	+	—	+	—
VR/immersive expt./serious game	≈	≈	—	—	+	—	≈	+
Lab experiment	—	≈	+	≈	+	+	≈	≈
Table top	≈	+	≈	+	≈	≈	≈	≈
Mental rehearsal	+	+	—	+	≈	—	≈	≈
Information session/walkaround	≈	+	≈	≈	≈	≈	—	+
Briefing	≈	+	≈	+	—	≈	—	≈
Control/free/scripted exercise	≈	≈	+	≈	≈	≈	—	+

— indicates a relative weakness in the model. + indicates a relative strength. ≈ indicates that the model performs neutrally in relation to the other models available.Abbreviation: VR, virtual reality.

faced, interact with the virtual space and perform actions (either through control of an avatar or through acting directly).[71–74] The scope and nature of this interaction is typically limited by the nature and sophistication of the technology available. There is an attempt to represent the conditions that might be faced in the scenario of interest (eg, in a real event). The realism of the experience is a factor in the credibility of the participant decisions taken and the measure of the task effectiveness. In recent years, the concept of serious gaming has been used within such environments—to more effectively represent the decision-making process within such an environment. These serious games allow decisions to be made under credible, controlled, and varied conditions, without exposing players to any physical risks, allowing more flexibility in scenario design.[75–77] Serious games have already been used for training purposes in the fire service.[78] Serious game players should be able to acquire some knowledge about emergency scenarios and improve their evacuation preparedness although the game experience, and/or assess the implications of such behaviour (eg, as part of an investigation, see the references herein[77,79–83]). However, the impact of the realism of the environment and the long-term effects of training using serious gaming has to be established.[80]

3. Laboratory experiment—Exposure of participants to a particular physical/psychological condition (ideally reflective of an evacuation) in a controlled artificial environment to assess performance of a specific task given the manipulation of this environmental condition.[23] This model represents a largely path-dependent decision-making process within an acknowledged artificial environment.
4. Table top exercise—Involves participants in a simulation of the decision-making process in response to the exercise scenario to test the effectiveness of the procedure tested and their part in it.[70] Should emergency responders be involved, then the table-top environment may be configured to simulate a command and control centre reflecting the physical setting under which these decisions might be made in a real incident; however, this would not be true of an evacuating population, where they involved in the exercise.
5. Mental rehearsal—Individual attempts to visualize expected decisions, tasks, and desired outcomes before the situation is experienced.[84–86] No attempt is made to create representative environmental conditions. The intention, here, is to enhance performance once the individual faces equivalent conditions. This approach has been used quite extensively in the context of training for physical activities, particularly in the area of sports coaching, although it has been shown to be effective in other contexts. Prompting the individual to initiate a mental rehearsal of an envisioned event has been shown to improve both success and speed of execution. This approach, which creates minimal risk to the participant, can be undertaken at any time by the individual and can represent a very low level of investment in training other than the individual participant's time.
6. Hot/cold debriefing—A review of the events, decisions, and outcomes produced during the event, including those involved and those monitoring it. Ministry of Civil Defence Emergency Management, New Zealand, recommends that 2 debriefs be conducted after a drill.[42] A hot debrief allows participants to provide feedback on the recent event—to recall key events while they are fresh in the memory. The more formal cold debrief is held a month or so later, allowing more reflection on the strengths and limitations of the event (after a more detailed analysis of observations is made) and then changes that need to be made to the procedure, tasks or the drill itself.[42]
7. Information session/workshop/seminar—Presentations/discussions held to engage the target population (individually, in groups or the entire population) to inform them of the scenarios that might occur, the conditions that might evolve,[3,5] the procedures in place, their role within them, and/or desirable outcomes. No attempt is made to recreate real-world actions or require the participants to simulate expected performance.
8. Walkaround—Participants (eg, evacuees) are guided around to the key locations, routes, decision points, and tasks by an experienced trainer/member of staff to familiarize them with the procedure and the activities that form it.[3] This walkaround will take place in the real-world environment and will involve the target population experiencing these spaces and situations passively—without having to take decision.

9. Control point exercise—Staff who have a role in an emergency procedure are positioned in locations in which they would be expected to operate during an incident.[5] Aspects of communication between these locations, individual familiarity with each of the spaces, and the individual's ability to operate at these locations can be examined.
10. Controlled/scripted exercise—Participants are taken through an exercise following an entirely scripted narrative. Essentially, participants are acting out their roles in one controlled instance—to identify example outcomes and stated decisions made.[5] This is unlikely to be in a real-world setting given the required "actor" interaction, but instead located in a single space where individual actors can more naturally communicate.
11. Free play exercise—In contrast to controlled or scripted exercises, actors are encouraged to role play after being provided with a set of initial conditions.[5] This expands on the table top exercise to possibly include an evacuating population. Participants actively engage in an attempt to reach a stated goal given the initial conditions provided. This event is likely located in a single space where individual actors can communicate.

In reality, a combination of these approaches (either in partial or complete form) may be adopted to complement an egress drill, given that they present a range of different strengths and weaknesses. It should be noted that the qualification of the impact/effectiveness of the models described in Table II is based on subjective estimates at this stage. It would require additional research prior to these assessments being used in earnest. This material is presented to outline the differences that might exist and how these may be used to differentiate between the approaches available.

An indication of the other models that might be used to assess/train the target population is shown in Table II (an extension on the work previously presented by Evacuation Planning Guide For Stadiums [70]). The column headings used in Table II reflect the key considerations identified in Section 6. Table II enables a comparison between the relative merits and limitations of these models and what they might contribute to population training and performance assessment. The limitations of an egress drill regarding the considerations outlined in Table II were described earlier in Section 6. This table extends that description to include the relative strengths and limitations of the 11 alternative models available. Cells with a "−" indicate a relative weakness in the model; a "+" symbol indicates a relative strength, and "≈" indicates that the model performs neutrally in relation to the other models available. This represents a crude and qualitative assessment of these models. However, these considerations are primarily intended to demonstrate that there are alternatives that have various capabilities and that these capabilities must be understood when assessing their relevance to the project at hand. For instance, a simulation tool causes little disruption to the organization with only a moderate possible financial cost (leading to the ≈ designation); it poses no risk or ethical concerns (+) and can repeatedly be used to explore a range of scenarios (+); however, it is often perceived as lacking credibility given that it is a relatively new tool (−) and has limited educational capacity, in and of itself (−). Virtual reality environments can elicit similarly sceptical views given their recent development and fashionable status (−), although they also have enhanced training capabilities (+). Table top exercises provide a flexible approach, allowing a range of scenarios to be explored (+); however, they provide moderate insights into the conditions produced—focusing on the decision-making process rather than the specific (physical) impact of these decisions within the evacuated space (≈). Walkthroughs, briefings and exercises pose little ethical concerns regarding participants (+); however, they are unlikely to be sufficiently repeated to produce statistically credible insights (−). Finally, mental rehearsals may produce reasonable benefits to individual performance (≈); however, it is a relatively recent development again provoking scepticism not aided by the lack of external scrutiny available (−).

It is apparent that these models have various strengths and weaknesses, and may also operate at different levels—informing or assessing the individual, group or population and relating to specific tasks or the entire procedure. As such, potential solutions may involve the use of several of these models to support the assessment and effective training of the target population[87]—to produce a more robust, informative, and representative training and assessment program.

An example may help demonstrate how these approaches might be used and the potential benefits.

Let us assume that we are developing the emergency plan for a office building with 5000 occupants.

The regulatory system with jurisdiction requires that this structure has quarterly full-building evacuation drills. A subset of the egress models outlined in Table II are combined to produce an alternative programme (labelled as Approach A) to assess performance and enhance occupant/staff familiarity with the emergency procedure in place. An outline of such a program is shown in Table III, formed from 10 procedural steps. Obviously, this is one of many approaches that might be adopted.

Table III includes several elements for each of the 10 suggested steps: the egress model used; the frequency with which this model is to be used; the objective of this employment, in terms of the target population and the intended impact; the possible disruption that this step will cause to building operation; and the overall cost of these steps in terms of the number of person hours lost per year, calculated from the size of the population involved over the year, the time taken for the step to be completed, and the number of times it is performed per year. As noted earlier, this cost could be balanced by a more quantitative estimate of the benefit of each step - if we had a clearer understanding of the impact of these tools on staff/evacuee performance (eg, the incremental increase in evacuee performance for each drill performed). In the absence of this knowledge, only the objective for each of the steps is stated, allowing a more qualitative assessment of what might potentially be achieved by each step.

Let us examine Step 1 in Table III as an example. The information session/walkaround is to be conducted once per year for each occupant. This will not involve all occupants at the same time but will be conducted individually or in small groups to reduce disruption, eventually addressing the entire population. Occupants walk through the routes that might be adopted during an emergency and then attend a seminar on the emergency procedure—the objectives, tasks, their role, resources, assumptions made, etc. As mentioned, given that the step will be applied to subsections of the population at any one time, the building will still be able to function as normal. Given that the entire population will be engaged over the course of the year and that the session is expected to last an hour, 5000 person. hours/year will be effectively "lost." The ongoing nature of this step (and others) also has the benefit of ensuring that emergency planning is seen to be a process rather than a one-off task.[87] Similar details on each of the 10 steps in the example training and assessment program is provided in Table III.

This type of analysis for each of the steps in a training and assessment program (eg, all 10 steps in Table III) allows us to determine the number of times the building functionality will be disrupted, the loss of time experienced by the population, the training and assessment tasks addressed, and the target groups/level of these tasks (individual, procedural, etc). From Table III, the overall "cost" of this approach is calculated as 35 500 person.hours/year, with one loss of building functionality per year.

If the building was required to be evacuated 4 times per year (Approach B), as is currently the case in some instances, then the equivalent cost for the same building would be 40 000 person.h/y (5000 people involved for 2 hours, 4 times per year), with a loss of building functionality 4 times per year (each of the 4 times that it is performed). In addition, if we assume that the drills were conducted in accordance with the regulatory frameworks highlighted earlier, the assessment would typically be made at the procedural level (with fewer requirements to assess individual performance during each of the trials) and fewer individual-level training elements to enhance this performance. In this example, Approach A is less costly in terms of person-hours per year lost during the emergency planning events, it has fewer interruptions to building operations and enables emergency planners to assess/enhance performance under a larger number of incident scenarios and at a greater number of levels (individual, procedural, etc). This is, of course, a simplification. In addition, there are a number of other approaches (ie, various combinations of the models highlighted) that might provide sufficient training and assessment whilst making more significant person-hour savings over multiple full building evacuations (ie, the more traditional approach suggested in Approach B) and reducing building functionality loss. However, it is hoped that this example illustrates the potential of using complementary approaches and of quantifying the relative costs of doing so.

8. DISCUSSION

The previous material highlighted several points: (1) approaches exist that can examine drill performance, (2) we have a reasonable understanding of the factors that contribute to evacuation

Table III. Training and assessment program using multiple models.

Step	Egress Model	Frequency	Objective	Disruption	Cost (#people × #hours × #repeats)
1	Information session/walkaround	Each occupant does this every year.	Individual level training: routes and systems available.	Individual/groups removed from routine activities. Building operational	$5000 \times 1 \times 1 =$ 5000 person.h/y No loss of building functionality.
2	Small-scale training (individual scripted exercise)	Each occupant does this every year.	Individual level training: individual training/familiarization of the procedure and their role within a given range of different scenarios.	Individual/groups removed from routine activities. Building operational.	$5000 \times 1 \times 1 =$ 5000 person.h/y No loss of building functionality.
3	Small-scale test: in procedure; eg, go to nearest exit, operate device, and identify alarm (individual drill)	Each occupant does this every year.	Individual level assessment: individuals/groups asked to enact role and their ability to perform expected tasks is assessed.	Individual/groups removed from routine activities. Building operational.	$5000 \times 1 \times 1 =$ 5000 person.h/y No loss of building functionality.
4	Table-top exercise	Each member of staff active in emergency plan does this twice per year.	Assessment—individual/ procedure: staff understanding and execution of procedure.	Staff removed from routine activities. Building operational.	$50 \times 2 \times 2 = 200$ person.h/y No loss of building functionality.
5	Seminar/review	Each member of staff active in emergency plan does this twice per year.	Assessment/familiarization: review of table top performance	Staff removed from routine activities. Building operational.	$50 \times 2 \times 2 = 200$ person.h/y No loss of building functionality.

Table III. *Continued*

Step	Egress Model	Frequency	Objective	Disruption	Cost (#people × #hours × #repeats)
6	Full-scale egress drill	Entire staff/occupant does this yearly.	Assessment—procedure: effectiveness to meet safety objectives given scenario examined.	Staff and occupant population removed from routine activities. Loss of Building Functionality.	5000 × 1 × 1 = 5000 person.h/y Loss of Building Functionality.
7	Hot debrief	Entire staff/occupant does this yearly.	Familiarization—individual/ procedure: review of drill conducted in small groups.	Groups of staff/ occupants removed from routine activities. Building operational.	5000 × 1 × 1 = 5000 person.h/y No loss of building functionality.
8	Egress simulation tool	Entire staff/occupant reviews results produced by simulation yearly.	Assessment—individual/ procedure: examine different scenarios to assess robustness/ effectiveness of procedure in place. Feedback suggests procedural enhancements and scenarios to be drilled.	Small number of staff removed from routine activities. Building operational.	2 × 50 × 1 = 100 person.h/y No loss of building functionality.
9	Immersive VR	Entire staff/occupant does this yearly.	Individual training/assessment: staff/occupants take part in range of virtual drills to train and assess under different scenarios (informed by step 8)	Groups of staff removed from routine activities. Building operational.	5000 × 1 × 1 = 5000 person.h/y No loss of building functionality.
10	Cold debrief	Entire staff/occupant does this yearly.	Training—procedural: assessment of performance in actual and virtual environments.	Staff removed from routine activities. Building operational.	5000 × 1 × 1 = 5000 person.h/y No loss of building functionality.

Abbreviation: VR, virtual reality.

performance, (3) numerous models exist to assess and inform evacuee performance, (4) regulatory frameworks vary in their requirements of egress drills, (5) the requirements provided by regulatory frameworks do not appear to be consistently followed to the same degree of detail, (6) it is impractical to assess and familiarize an entire population during an evacuation drill, and (7) there are several application areas that use several egress models that are less disruptive and more informative (to the evacuee and to the safety manager) than a full-scale drill.

As has been evident during the previous sections, we have been extremely cautious in our characterization and criticism of egress drills. This is for good reason: the very last thing that we intend is to reduce the emphasis on life safety, or reduce the number of weapons in the safety manager's armoury. However, we do argue that egress drills might be undermined when they are not used in a cost-effective manner to demonstrate/facilitate improved evacuee performance.

We suggest that there might be more effective approaches to familiarize a population and assess egress performance—that involve the use of egress drills along with other egress models, as has been used in adjacent application areas. This may reduce cost and disruption, facilitate more detailed assessment and ensure that the individual and the population is more familiar and practiced in relevant aspects of the emergency procedure in place.

Although we do not suggest a definitive combination of egress models, we do identify a set of models that might be used to assess or enhance performance. These might be used according to the occupancy and the scenarios faced. We believe that the benefits of this combined approach should be examined more closely—to determine improvement in performance, cost, implementation, practicality, and provide clear implementation guidance. At the very least, this examination will help enhance the employment of egress drills in the future.

Of course, the approach suggested here does not address issues of third party supervision and oversight, which would benefit current and future approaches. The absence of such scrutiny in any approach undermines the credibility of results produced. Similarly, clear implementation guidance should be provided on the models to be used (drill, computer, or otherwise), how such models should be used (configuration, execution, data collection, etc) and how the results should be compiled and reported. This, along with third party scrutiny, would enhance the consistency between model applications and increase the credibility and value of the entire process. Improvements in oversight will address some of the issues raised, but not all of them—building managers and safety officers should follow guidance that enhances performance and determines that the necessary performance level has been reached. For this we need better oversight and implementation guidance that ensures the most effective tools are applied to enhance life safety performance.

9. CONCLUSION

The egress drill model is a critical tool for both enhancing and assessing evacuation performance when performed appropriately. Drills have often been used to provide insight into evacuation performance and to aid in the training process with great effect. This article in no way attempts to undermine the importance of the egress drill or suggest that they should not be performed. However, the article has identified a number of issues that inherently limit the reach and realism of these egress drills. Current practice would be enhanced through a greater appreciation of the strengths and limitations of egress drills—so that they can be conducted in a more informed manner—in conjunction with more consistent and effective performance monitoring. We must (1) exploit the drills to their full potential, especially given their cost and the important insights gained from their performance and (2) avoid issues that might be introduced by drills, such as occupant complacency through overdrilling and drilling to unrealistically benign scenarios providing a false sense of security. The lack of relevant research on the effectiveness and repeated use of drills is a key limiting factor in drill design and execution. It is suggested that other models could be used to complement the performance of egress drills—to provide additional insight and confidence in the results produced and also expand the scenarios examined without increasing the number of drills required or subsequent disruption. This could be achieved without compromising the twin objectives of egress drills: training and assessment. This might be especially useful where the challenges posed by drill performance are too great to generate useful results. It is hoped that the exploration of these alternatives in the future might assist emergency planners in their difficult role and eventually enhance life safety.

ACKNOWLEDGEMENTS

Steven Gwynne would like to acknowledge Ahmed Kashef (NRC), Lisette Seguin (NRC), and Aoife Hunt (AECOM) for their input during the review of this article.

REFERENCES

1. Guidelines to Developing Emergency Action Plans for All-Hazard Emergencies in High-Rise Office Buildings, National Fire Protection Association, 2014.
2. Berlin JM, Carlström ED. Collaboration exercises: what do they contribute?—a study of learning and usefulness. *Journal of Contingencies and Crisis Management* 2015; **23**(1):11–23.
3. Renner S. Emergency exercise and training techniques. *Australian Journal of Emergency Management* 2001:26–35 Winter.
4. Borodzicz, E and van Haperen, K. Individual and group learning in crisis simulations, Discussion Papers in Management, University of Southampton, #M02-5 2002.
5. Exercise Planner's Guide, HMSO, 1998.
6. OECD Obesity Update 2014; 2014.accessed at: http://www.oecd.org/els/healthsystems/ObesityUpdate2014.pdf.
7. United Nations, Department of Economic and Social Affairs, Population Division World Population Prospects: The 2015 Revision, Volume I: Comprehensive Tables. ST/ESA/SER.A/379. ST/ESA/SER.A/379. United Nations, NY 2015.
8. United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2015 Revision, Key Findings and Advance Tables. ESA/P/WP.241. ST/ESA/SER.A/380.United Nations, NY, 2015.
9. Fioretti G. Agent-based simulation models in organization science. *Organizational Research Methods* 2013; **16**:227.
10. ISO/TS 29761:2015: fire safety engineering—selection of design occupant behavioural scenarios, in development by ISO TC92/SC4/WG11 TG.
11. Report of the Auditor General of Canada Chapter 3: Health and Safety in Federal Office Buildings, 2009.
12. Sinclair H, Doyle EE, Johnston DM, Paton D. Assessing emergency management training and exercises. *Disaster Prevention and Management: An International Journal* 2012; **21**(4):507–521.
13. Gwynne SMV. Helping people on their own terms: developing inclusive emergency procedures. *Fire Technology* 2008; **44**(4):439–461.
14. Klein G. *Sources of Power: How People Make Decisions*. MIT Press: Cambridge, MA, 1999 ISBN 0-262-61146-5.
15. Operational Physiological Capabilities of Firefighters: Literature Review and Research Recommendations Fire research technical report 1/2005, optimal performance limited on behalf of the Office of the Deputy Prime Minister, 2005.
16. Physiological Assessment of Firefighting, Search and Rescue in the Built Environment Fire research technical report 2/2005, optimal performance limited, on behalf of the Office of the Deputy Prime Minister, 2004.
17. Hays RT, Jacobs JW, Prince C, Salas E. Flight simulator training effectiveness: a meta-analysis. *Military Psychology* 1992; **4**(2).
18. Hamilton R. Nurses' knowledge and skill retention following cardiopulmonary resuscitation training: a review of the literature. *Journal of Advanced Nursing* 2005; **51**(3):288–297.
19. Kaye W, Rallis SF, Mancini ME, Linhares KC, Angell ML, Donovan DS, Zajano NC, Finger JA. The problem of poor retention of cardiopulmonary resuscitation skills may lie with the instructor, not the learner or the curriculum. *Resuscitation* 1991; **21**:67–87.
20. Yang C-W, Yen Z-S, McGowan JE, Chen HC, Chiang W-C, Mancini ME, Soar J, Lai M-S, Huei-Ming M. A systematic review of retention of adult advanced life support knowledge andskills in healthcare providers. *Resuscitation* 2012; **83**:1055–1060.
21. Hamilton, R Nurses' knowledge and skill retention following cardiopulmonary resuscitation training: a review of the literature, Integrative Literature Reviews and Meta-Analyses, 2004.
22. Proulx, G, Laroche, C, and Pineau, J. Methodology for evacuation drill studies. Internal Report 730, NRC, 1996.
23. Gwynne, SMV. Conventions in the collection and use of human performance data. NIST GCR 10-928, National Institute of Standards and Technology, 2010.
24. Proulx, G. The time delay to start evacuating upon hearing a fire alarm. Proceedings of Human Factors and Ergonomics Society. 38th Annual Meeting, 1994.
25. Kholshevnikov VV, Samoshin DA, Parfyonenko AP, Belosokov IP. Study of children evacuation from pre-school education institutions. *Fire and Materials* 2012; **36**:349–366 https://doi.org/10.1002/fam.2152, John Wiley and Sons Ltd., UK.
26. Proulx G, Fahy R. The time delay to start evacuation: review of five case studies. In *Proceedings of the 5th International Symposium*, Hasemi Y (ed). International Association Fire Safety Science, 1997; 783–794.

27. Kagawa M, Kose S, Morishita Y. Movement of people on stairs during fire evacuation drill-Japanese experience in a high-rise office building. In *Proceedings of the 1st International Symposium*, Grant CC, Pagni PJ (eds). IAFSS: Gaithersburg, Maryland, 1985; 533–540.
28. Peacock RD, Reneke PA, Kuligowski ED, Hagwood CR. Movement on stairs during building evacuations. *Fire Tech* 2016:1–27.
29. Lárusdóttir, AR, Dederichs, A. Behavioural aspects of movement down stairs during elementary school fire drills. In: Proceedings of fifth international symposium human behaviour in fire, Downing College Cambridge, 19th – 21st September 2012. Interscience Communications 2012; 120–127.
30. Ono, R, Valentin, M, Vittorino, F Walking speed data of fire drills at an elementary school. In: Proceedings of 5th international symposium human behaviour in fire, Downing College Cambridge, 19th – 21st September 2012. Interscience Communications 2012; 98–108.
31. Proulx G. Evacuation time and movement in apartment buildings. *Fire Safety Journal* 1995; **24**(3):229–246.
32. Gwynne SMV, Boswell DL. Pre-evacuation data collected from a mid-rise evacuation exercise. *Journal of Fire Protection Engineering* 2009; **19**(1):5–29.
33. Gwynne S, Galea ER, Parke J, Hickson J. The collection and analysis of pre-evacuation times derived from evacuation trials and their application to evacuation modeling. *Fire Tech.* 2003; **39**(2):173–195.
34. Tavares RM, Gwynne S, Galea ER. Collection and analysis of pre-evacuation time data collected from evacuation trials conducted in library facilities in Brazil. *J App. Fire Sci.* 2006; **15**(1):23–40.
35. Gwynne SMV. *Optimising Fire Alarm Notification for High Risk Groups: Summary Report*. The Fire Protection Research Foundation: Quincy, MA, USA, 2007; 127.
36. Samochine DA, Boyce K, Shields J. An investigation into staff behaviour in unannounced evacuations of retail stores – implications for training and fire safety engineering. In *Proceedings of the 8th International Symposium*, Gottuk DT, Lattimer BY (eds). International Association Fire Safety Science, 2005; 519–530.
37. Galea, ER, Deere, S, Sharp, G, Filippidis, L, Hulse, L. Investigating the impact of culture on evacuation behavior. In: Proceedings of the twelfth international conference Interflam 2010, Vol. 1, pp. 879–892. *Interscience Communications*, ISBN 978-0-9541216-5-5.
38. Kuligowski E, Peacock R, Wiess E, Hoskins B. Stair evacuation of older adults and people with mobility impairments. *Fire Safety Journal* 2013; **62**(C):230–237.
39. Lovreglio R, Ronchi E, Borri D. The validation of evacuation simulation models through the analysis of behavioural uncertainty. *Reliability Engineering & System Safety* 2014; **131**:166–174. https://doi.org/10.1016/j.ress.2014.07.007.
40. Lovreglio R, Ronchi E, Nilsson D. A model of the decision-making process during pre-evacuation. *Fire Safety Journal* 2015; **78**:168–179. https://doi.org/10.1016/j.firesaf.2015.07.001.
41. Lovreglio R, Ronchi E, Nilsson D. An evacuation decision model based on perceived risk, social influence and behavioural uncertainty. *Simulation Modelling Practice and Theory* 2016; **66**:226–242. https://doi.org/10.1016/j.simpat.2016.03.006.
42. MCDEM CDEM exercises: directors guidelines for Civil Defence Emergency Management (CDEM) groups [DGL 10/09], 2009.
43. Thiagarajan S. How to maximize transfer from simulation games through systematic debriefing. In *Developing Transferable Skills in Education and Training*, Percival F, Lodge S, Saunders D (eds). Kogan Page: London, Philadelphia, 1993; 47–52.
44. NFPA. *101: Life Safety Code® Handbook* (2015th edn). National Fire Protection Association: USA, 2015.
45. Regulatory Reform (Fire Safety) Order Office—Deputy Prime Minister, HMSO 2005, UK, 2005.
46. Statutory rules of Northern Ireland, No. 235 health and safety fire safety, the fire safety regulations (Northern Ireland) HMSO 2010, UK, 2010.
47. Scottish statutory instruments no. 456 fire safety, fire safety (Scotland) regulations HMSO, 2006.
48. Home Office, Fire safety law and guidance documents for business - accessed at https://www.gov.uk/government/collections/fire-safety-law-and-guidance-documents-for-business, 2012.
49. Managing fire safety in the workplace, health and safety works NI and Northern Ireland fire and rescue service 2011.
50. BS 9999. *Code of Practice for Fire Safety in the Design, Management and use of Buildings*. British Standards Institution: London UK, 2008.
51. 2012 International Fire Code (International Code Council Series). International Code Council (distributed by Cengage Learning), 2011.
52. National Fire Code of Canada 2010.
53. Section 21B Part 2, Owner must provide and maintain evacuation scheme for relevant building, Fire Service Act 1975, Public Act 1975 No. 42, Reprint 2013, Parliamentary Counsel Office, New Zealand Legislation.
54. Fire Safety and Evacuation of Buildings Regulations (SR 2006/123), Reprint as at 1 July 2013, Parliamentary Counsel Office, New Zealand Legislation, 2006.
55. Robbins, AP and Warren J. Accessible egress pilot workshops summary, study report 338. BRANZ Ltd., Judgeford, New Zealand, 2015.
56. D. Lgs 81/2008 and il DM 10/03/1998.
57. SRVFS 2004; 3
58. AFS 2001; 1
59. Räddningstjänstensyd 2007
60. AFS 1993; 56

61. Kuligowski, E. Terror Defeated: Occupant Sensemaking, Decision-Making and Protective Action in the 2001 World Trade Center Disaster. Ph.D. Dissertation., Boulder, CO: University of Colorado at Boulder, 2011.
62. Kuligowski, ED. NIST Technical Note 1632: the process of human behavior in fires, National Institute of Standards and Technology, Gaithersburg, MD, 2009.
63. Gwynne S, Kinsey MJ, Hulse LM. Guidance for the model developer on representing human behavior in egress models. *Fire Technology* 2016; **52**(4):775–800.
64. Sokolowski JA, Banks MB. *Modeling and Simulation Fundamentals*. Wiley and Sons, 2010.
65. Proulx G. A stress model for people facing a fire. *Journal of Environmental Psychology* 1993; **13**:137–147.
66. Wilson HC. Emergency response preparedness: small group training part 1—training and learning styles. *Disaster Prevention and Management* 2000; **9**(2):105–116.
67. Gwynne S, Galea ER, Owen M, Lawrence PJ, Filippidis L. A review of the methodologies used in evacuation modelling. *Fire and Materials* 1999; **23**(6):383–389.
68. Kuligowski, ED and Gwynne, SMV. What a user should know about selecting an evacuation model, Fire Protection Engineering Magazine. Human Behaviour in Fire Issue, 2005.
69. Kuligowski, ED, Peacock, RD and Hoskins, BL. A review of building evacuation models. NIST Technical Note 1680. November, 2010.
70. Evacuation Planning Guide For Stadiums Dept. for Homeland Security, 2008.
71. Chittaro L, Buttussi F. Assessing knowledge retention of an immersive serious game vs. a traditional education method in aviation safety. *IEEE Transactions on Visualization and Computer Graphics* 2015; **21**(4):529–538.
72. Chittaro L, Sioni R. Serious games for emergency preparedness: evaluation of an interactive vs. a non-interactive simulation of a terror attack. *Computers in Human Behavior* 2015; **50**(September 2015):508–519.
73. Crescentini C, Chittaro L, Capurso V, Sioni R, Fabbro F. Psychological and physiological responses to stressful situations in immersive virtual reality: differences between users who practice mindfulness meditation and controls. *Computers in Human Behavior* 2016; **59**(June 2016):304–316.
74. Gamberini L, Chittaro L, Spagnolli A, Carlesso C. Psychological response to an emergency in virtual reality: effects of victim ethnicity and emergency type on helping behavior and navigation. *Computers in Human Behavior* 2015; **48**:104–113.
75. Cha M, Han S, Lee J, Choi B. A virtual reality based fire training simulator integrated with fire dynamics data. *Fire Safety Journal* 2012; **50**:12–24. https://doi.org/10.1016/j.firesaf.2012.01.004.
76. Smith SP, Trenholme D. Rapid prototyping a virtual fire drill environment using computer game technology. *Fire Safety Journal* 2009; **44**:559–569. https://doi.org/10.1016/j.firesaf.2008.11.004.
77. Rüppel U, Schatz K. Designing a BIM-based serious game for fire safety evacuation simulations. *Adv. Eng. Informatics* 2011; **25**:600–611. https://doi.org/10.1016/j.aei.2011.08.001.
78. Williams-Bell FM, Kapralos B, Hogue A, Murphy BM, Weckman EJ. Using serious games and virtual simulation for training in the fire service: a review. *Fire Technology* 2015; **51**:553–584. https://doi.org/10.1007/s10694-014-0398-1.
79. Lovreglio R. *Modelling Decision-Making in Fire Evacuation Using the Random Utility Theory*. Politecnico of Bari: Milan and Turin, 2016.
80. Girard C. Ecalle J, Magnan A. Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning* 2013; **29**:207–219. https://doi.org/10.1111/j.1365-2729.2012.00489.x.
81. Aldrich C. *The Complete Guide to Simulations and Serious Games: How the Most Valuable Content Will be Created in the Age Beyond Gutenberg to Google*. John Wiley & Sons, UK, 2009.
82. Almeida, JE. Serious games as a behaviour elicitation tool: applications to evacuation scenarios. University of Porto, 2016.
83. Kobes M, Helsloot I, de Vries B, Post JG, Oberijé N, Groenewegen K. Way finding during fire evacuation; an analysis of unannounced fire drills in a hotel at night. *Building and Environment* 2010; **45**:537–548. https://doi.org/10.1016/j.buildenv.2009.07.004.
84. Mendoza D, Wichman H. "Inner" darts: effects of mental practice on performance of dart throwing. *Perceptual and Motor Skills* 1978; **47**(3 Pt 2):1195–1199.
85. Epstein ML. The relationship of mental imagery and mental rehearsal to performance of a motor task. *Journal of Sport and Exercise Psychology* 1980; **2**(3):211–220.
86. Ryan ED, Simons J. Cognitive demand, imagery, and frequency of mental rehearsal as factors influencing acquisition of motor skills. *Journal of Sport Psychology*, 1981 1981; **3**:35–45.
87. Gwynne SMV. *Drilling for Safety, RR-384*. Canada: National Research Council of, 2015.